How Does Explicit Versus Implicit Risk Information Influence Adolescent Risk-Taking Engagement?

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Abstract

Adolescents have been shown to be more likely to engage in risky behaviors in daily life. Many studies have indicated that adolescents could make advantageous choices when they received explicit information but failed to choose advantageously when they were not informed about risks. The current study aimed to examine the influence of explicit risk information (i.e. when risk information is directly available) *vs* implicit risk information (i.e. when risk information has to be learned from feedback) on risk-taking engagement in order to clarify whether the enhanced risk-taking observed in decision making under ambiguity in adolescents results from either a greater exploration of ambiguous situations (i.e., a higher ambiguity tolerance) or a specific difficulty associated with learning based on previous choices' outcomes. Adolescents and young adults completed a new adaptation of the BART. They were required to accumulate as many points as possible by inflating balloons associated with variable break points and avoiding explosions. This adaptation involved a manipulation of the information level with two conditions, an "informed" condition and a "non-informed" condition, in which the participants had to learn the matching of colors with balloons' resistances based on feedback. The results demonstrated that providing explicit risk information allows adolescents to be as efficient as adults at the end of the game. In contrast, adolescents failed to adjust risk-taking to the balloon resistance in the non-informed condition. These findings critically suggest that this failure reflects a specific impairment of feedback-based learning ability but not a global excess of risk-taking during adolescence.

Keywords: Adolescent, Risk-taking, Information level, Learning, BART.

In daily life situations, adolescents are likely to engage in risky behaviors, such as substance or alcohol abuse, reckless automobile driving or unprotected sex (Casey, Getz, & Galvan, 2008; Galvan, Hare, Voss, Glover, & Casey, 2007; Spear, 2000; Steinberg, 2008; Steinberg & Monahan, 2007). Although most intervention programs consist in providing information regarding the risks of these behaviors and their potential negative consequences (Reyna & Farley, 2006), to the best of our knowledge, few experimental studies have examined the effect of providing explicit risk information versus not providing such information directly (i.e., when risk information has to be learned from feedback) on adolescent risk-taking behaviors. Nevertheless, previous investigations have indicated that adolescents could make advantageous choices in terms of expected value when they received explicit information (i.e., decision making under risk when decision makers can assign a probability of occurrence to each of the outcomes, see for example Falk & Wilkening, 1998; Reyna & Farley, 2006; Schlottmann, 2001; van Leijenhorst, Westenberg, & Crone, 2008); however, they failed to choose advantageously when they were not explicitly informed (i.e., decision making under ambiguity in which some information about the probabilities of the potential outcomes is not directly available; Aïte et al., 2012; Cassotti, Houdé, & Moutier, 2011; Crone & van Der Molen, 2007). To explain this specific failure in decision making under ambiguity during adolescence, some studies have suggested that adolescents present an increased tolerance for ambiguity exploration (Tymula et al., 2012), whereas others studies have assumed a feedback-learning impairment during adolescence. Therefore, the current study aimed 1) to directly examine the potential impact of explicit risk information (i.e. when risk information is directly available) *vs* implicit risk information (i.e. when risk information is not directly available but has to be learned from feedback) on risk-taking engagement, and 2) to clarify whether the enhanced risk-taking observed in decision making under ambiguity in adolescents results from either a greater exploration of ambiguous situations (i.e., a higher ambiguity tolerance) or a specific difficulty associated with learning based on previous choices' outcomes.

Converging evidence from experimental developmental studies has demonstrated that adolescents exhibit cognitive decision-making capacities that are comparable to those of adults when information regarding the probabilities of the potential outcomes is provided (Falk & Wilkening, 1998; Reyna & Farley, 2006; Schlottmann, 2001; van Leijenhorst, Westenberg, & Crone, 2008). Although developmental studies reported that 5- to 7-year-old children were less able to adjust their risk-taking based on expected value differences than adults in decision making under risk (Levin, & Hart, 2003; Levin, Weller, Pederson, & Harshman, 2007; Weller, Levin, & Denberg, 2011), another investigation revealed that participants aged 8 years and older perform similarly to adults with respect to both the level of risk and the magnitude of potential gains and losses in the decision-making process (van Leijenhorst et al., 2008). In contrast, children's and adolescents' ability to distinguish between advantageous (i.e., leading to overall gain in the long term) and disadvantageous (i.e., leading to overall loss in the long term) options remains suboptimal compared with that of adults when information regarding the risk level of the potential outcomes is not explicitly provided. Typically, studies using child-friendly adaptations of the Iowa Gambling Task (IGT), a task specifically designed to assess decision-making under ambiguity ability, have reported that adolescents exhibit a strong bias in favor of disadvantageous options, whereas adults learn to choose less attractive but advantageous options in the long term during the course of the task (Aïte et al., 2012; Cassotti et al., 2014, 2011; Crone & van der Molen, 2004; Crone & Van Der Molen, 2007; Hooper, Luciana, Conklin, & Yarger, 2004; Overman et al., 2004). Taken together, these results suggest that adolescents are efficient in the estimation of the probability and the evaluation of the potential outcomes of a choice in decision-making under risk when explicit information is available; however, adolescents showed difficulties in considering these two dimensions in decision-making under ambiguity when such information is not provided and must be inferred from experience.

In a series of behavioral studies, van Duijvenvoorde and colleagues directly examined the impact of information level on adolescents' abilities to make advantageous choices in decision-making. For example, van Duijvenvoorde, Jasen, Bredman & Huizenga (2011) compared the performances of participants aged 7 to 29 years in two versions of a decision-making task that involved feedback reception: an informed version and a non-informed version. In the non-informed version of the Gambling Game, which is a child-friendly adaptation of the Iowa Gambling Task, participants are instructed to collect as many points as possible by selecting among four possible machines labeled A, B, C, and D. Similarly to the original IGT, the four machines systematically differ in the amount of gain, amount of loss, and frequency of loss such that to succeed at this game, participants must withdraw from disadvantageous choices in the long-term machines (A, B) and opt for advantageous choices in the long-term machines (C, D). Critically, the schedule of rewards and losses associated with each machine are not disclosed in the non-informed condition (i.e., decision making under ambiguity) and should be gradually learned from the feedback obtained during the game. In contrast, participants received explicit information to estimate the probabilities and the amount of gains and losses in the informed version of the Gambling Game (i.e., decision making under risk). Although all age groups exhibited a preference for the advantageous options when they received explicit information in the informed condition, children failed to make advantageous choices until the age of 12 in the non-informed version of the Gambling Game. The authors concluded that the developmental trajectories of long-term and working memory could lead to feedback-based learning impairment in non-informed decision making during adolescence (van Duijvenvoorde, Jansen, Bredman, & Huizenga, 2011; see also van Duijvenvoorde, Jansen, Visser, & Huizenga, 2010). In line with this body of research, the enhanced risk-taking engagement observed during adolescence might result from adolescents' difficulty to adjust their behaviors by learning based on previous feedback.

Nonetheless, an alternative interpretation for an excess of risk-taking during adolescence might be that adolescents exhibit an increased tolerance for ambiguous situations. Empirical support for this hypothesis was provided by a recent study (Tymula et al., 2012) showing that adolescents are less ambiguity averse than adults. Using a task involving a series of choices between sure options and options associated with various ambiguity levels (i.e., options for which associated probabilities are partially unknown), the authors demonstrated that adolescents more frequently explored the ambiguous alternatives than adults did. According to the authors, greater curiosity "about the world that surrounds them" could lead adolescents to an excessive exploration of ambiguous situations.

Thus, the aim of the current study was to expand on previous investigations by van Duijvenvoorde and colleagues to 1) clarify the influence of explicit *vs* implicit risk information (i.e. informed *vs* non-informed) in risk-taking engagement during adolescence and 2) to determine whether adolescents present an impairment of feedback-based learning ability or an increased tolerance for ambiguity exploration. Note that these two potential interpretations (i.e. the impairment of feedback-based learning ability or the increased tolerance for ambiguity exploration) cannot be directly tested using the IGT or adaptation of the IGT such as the Gambling Game of van Duijvenvoorde and colleagues. Indeed, previous studies have indicated that children and adolescents have difficulties inhibiting an automatic tendency to switch to another option after they experienced a loss, decreasing the deep exploration of specific ambiguous option compared with that observed in adults (Aïte et al., 2012; Cassotti et al., 2011; Cassotti et al., 2014).

Consequently, we designed a new adaptation of the Balloon Analogue Risk Task (BART) (Lejuez et al., 2002) inspired from the Balloon Emotional Learning Task (BELT) (Humphreys, Lee, & Tottenham, 2013) that involved a manipulation of the information level with two conditions: an "informed" condition, in which the risk level is provided to the participants, and a "non-informed" condition, in which the risk level is unknown and must be inferred from feedback. In this task, participants are required to accumulate as many points as possible by inflating three types of balloons associated with variable break points (i.e., low-resistance, medium-resistance, and high-resistance). Participants can save the accumulated points at any moment; however, if the balloon explodes first, all accumulated points are lost. In the "informed" condition of the present study, the participants received explicit information regarding the balloon resistances (i.e., low-resistance, medium-resistance, and high-resistance), whereas they had to learn to estimate the risk level based on feedback in the "non-informed" condition.

The BART was initially designed to provide an experimental measure of risk-taking engagement in adolescents and adults. Numerous studies have crucially reported that riskiness in the BART was positively related to the self-reported occurrence of real-life risky behaviors (Cavalca et al., 2013; Dean, Sugar, Hellemann, & London, 2011; Lejuez, Aklin, Zvolensky, & Pedulla, 2003). Moreover, this task differs from other decision-making tasks such as the IGT, in which the "risky choices" refer to the disadvantageous options (i.e., options with lower overall expected value associated with attractive gains but also larger losses, see Bishara et al., 2009). In contrast, some level of risk is adaptive in the BART: It involves risky behavior for which riskiness is rewarded up to an unpredictable point at which further riskiness results in poorer outcomes leading to an explosion. Thus, risk level increases cumulatively with pumps as in many real-world situations involving such cumulative risk probabilities (Bornovalova et al., 2009; Lejuez et al., 2002). In contrast with the IGT, the level of exploration of each ballon in the BART is not influenced by a reactive response pattern to losses (i.e. the tendency to switch to another option after they experienced a loss, see Cassotti et al., 2014).

In line with previous studies (Aïte et al., 2012; Cassotti et al., 2014; Crone & Van Der Molen, 2007; Van Duijvenvoorde et al., 2011), we assumed that developmental differences between adolescents and adults would be limited to the non-informed version of the BART. We further reasoned that if adolescents demonstrate an increased tolerance for ambiguity and thus explore ambiguous options to a greater extent, then they should exhibit increased risk-taking engagement in the non-informed BART compared with adults from the first to the last stages of the task and regardless of the balloon resistances (Tymula et al., 2012). In contrast, if adolescents fail to infer the risk level from feedback in the non-informed condition (van Duijvenvoorde et al., 2011), developmental differences should emerge throughout the task. Before learning (i.e., the first stage of the task), adolescents and adults should perform the task at the same level. However, in the latter stages (i.e., when learning is allowed by the reception of feedbacks), adolescents should not present a general excess of risk taking, but they should fail to adjust behaviors to the balloons' resistance compared with adults: They should take more risk for the breakable balloons (i.e., low-resistance balloons), and they should take less risk for the most resistant balloons (i.e., high-resistance balloons).

Methods

Participants

Eighty-seven participants were recruited in the current investigation. They were divided into two age groups: 45 adolescents aged 14 to 16 years ($M = 14.71$, $SD = .69$) and 42 young adults aged 20 to 25 years ($M = 21.86$, $SD = 1.53$). The adolescents were recruited from a secondary school, and the adults were first-level students at Paris Descartes University. The participants were randomly assigned to one of two information-level conditions: an informed condition and a non-informed condition.

Table 1 displays the sex and mean age distributions for the age groups and each experimental condition. ANOVA and Chi-squared analyses indicated that the mean age ($F(1,83) = .10$, $p = .75$) and sex (adolescent: $\chi^2 = 1.70$, $p = .30$; adult: $\chi^2 = 0$, $p = 1$) were not significantly different between the informed and non-informed conditions.

[TABLE 1]

Design and procedure

All participants completed a new computerized decision-making task adapted from the BART (Lejuez et al., 2002) and the BELT (Humphreys et al., 2013). This adaptation was designed to measure risk-taking engagement in both informed and non-informed situations. To earn as many points as possible, participants must inflate balloons and avoid explosions.

At the start of each trial, a small simulated balloon was presented on the screen. The participants were required to inflate the balloon to win chips of various values (i.e., 1, 5 or 10 points). Each left-click inflated the balloon and was rewarded with a chip collected in a temporary bank. The number of points accumulated in the temporary bank was indicated on the screen under the balloon. The balloons could explode at any time. If the participant pumped the balloon beyond the break point, he lost the entire temporary bank. A "pop" sound was subsequently generated, and the next uninflated balloon appeared. Prior to an explosion, the participant can transfer (with a right-click) all points from the temporary bank to a definitive bank (depicted on the top of the screen), which leads to the next balloon (Figure 1).

In this adaptation, 3 balloon colors were used (i.e., blue, yellow and pink) to refer to three distinct probabilities of explosion (i.e., low-resistance, medium-resistance, and high-resistance). The low-resistance balloons were constrained to randomly explode between 3 and 7 pumps, the medium-resistance balloons between 8 and 12 pumps and the high-resistance balloons between 13 and 17 pumps. We informed the participants that balloons' colors referred to the different probabilities of explosion. The matching of resistance with colors was counterbalanced. We also manipulated two information level conditions but features of explosion probabilities were strictly constant between informed and non-informed conditions.

In the informed condition, a gauge depicted categorical information about the balloons' resistance. The proportion of red or green in the gauge reflected the 3 levels of resistance (a large majority of red indicated the low-resistance balloons, half red and half green indicated the middle-resistance balloons, and a large majority of green indicated the high-resistance balloons). In the informed condition, the participants could use the gauge such that they did not have to determine the matching of the colors with resistance levels (i.e. explicit information). In contrast, in the non-informed condition, a grey cover masked the gauge. Thus, the participants had to learn the matching of the colors with resistance levels based on the feedback the received.

Ninety balloons were pseudo-randomly presented with 10 repetitions of the combined 3 resistance levels (low, medium, or high) and 3 chip values (1, 5 or 10 points). The trials were distributed and randomly ordered in 5 blocks, including 2 repetitions of the resistances and chip values combination in each bloc.

[FIGURE 1]

Results

Pump analysis

To examine risk-taking engagement throughout the game in the informed and non-informed situations, we analyzed the number of pumps as the primary dependent measure that informed of participants' risk engagement.

We focused on the start of the game (the first 18 balloons, block 1) and the end of the game (the last 18 balloons, block 5) to distinguish risk-taking before learning and after potential feedback-based learning. We conducted an analysis of variance (ANOVA) with age (2: adolescents and adults), information level (2: informed and non-informed) and gender (2: male and female) as the three between-subject factors and balloon resistance (3: low-resistance, medium-resistance, and high-resistance) and chip value (3: small, medium and large value) as the two within-subject factors. We used partial eta squared (ηp2) and Cohen's d to assess the effect size.

Beginning of the game

The ANOVA identified a main effect of balloon resistance, which indicated an increase in pump number with resistance, $F(2,158) = 194.77$, $p < .001$, $\eta_p^2 = .71$, (low-resistance: $M = 3.81$, $SD = .95$; medium-resistance: $M = 6.20$, $SD = 1.48$; and high-resistance: $M = 8.14$, $SD = 2.47$) and a main effect of chip value, $F(2,158) = 17.19$, $p < .001$, $\eta_p^2 = .18$. Planned contrasts indicated fewer pumps for large values than for small values, $t_{(86)} = 3.59$, $p < .001$, $d = .77$, and medium values, $t_{(86)} = 5.74$, $p < .001$, $d = 1.24$, (Small: $M = 6.12$, $SD = 1.32$; Medium: $M = 6.39$, *SD* = 1.58; Large: *M* = 5.66, *SD* = 1.38). There was no main effect of gender, $F(1,79) < 1$ or information level, $F(1,79) < 1$; or age, $F(1,79) < 1$, but a resistance x information level interaction, $F(2,158) = 18.74$, $p < .001$, $\eta_p^2 = .19$. Critically, there was neither an age x information level interaction, $F(1,79) < 1$, nor an age x resistance x information level interaction, $F(2,158) = 1.19$, $p = .31$, (Figure 2). Finally, this interaction was not modulated either by gender, $F(2,158) = 1.31$, $p = .27$, or chip value, $F(4,316) = 1.70$, $p = .15$.

End of the game

The ANOVA identified a main effect of balloon resistance, $F(2,158) = 353.99$, $p <.001$, $\eta_p^2 = .82$, which indicated that the number of pumps increases with resistance (low-resistance: *M* = 3.58, *SD* = 1.08; medium-resistance: *M* = 7.08, *SD* = 1.54; and high-resistance: *M* = 9.81, *SD* = 2.73) and a main effect of chip value, $F(2,158) = 3.59$, $p < .05$, $\eta_p^2 = .04$, which indicated fewer pumps for large values than for medium values, $t_{(86)} = 2.86$, $p < .01$, $d = .61$, (Small: *M* = 6.88, *SD* = 1.30; Medium: *M* = 6.95, *SD* = 1.49; Large: *M* = 6.64, *SD* = 1.47). However, there was no main effect of gender, $F(1,79) = 1.63$, $p = .21$; age, $F(1,79) < 1$; or information level, $F(1,79) = 1.02$, $p = .31$. There was a resistance x information level interaction, $F(2,158) = 13.04$, $p < .001$, $\eta_p^2 = .14$, and a resistance x age interaction, $F(2,158) = 4,21$, $p < .05$, $\eta_p^2 = .05$, but critically, there was a significant age x resistance x information level interaction, $F(2,158) = 5.01$, $p < .01$, $\eta_p^2 = .06$, that was not modulated either by gender, $F(2,158) < 1$, or chip value, $F(4,316) < 1$. This three-way interaction is presented in Figure 2 and was followed up using two independent ANOVAs for the informed and non-informed conditions.

In the informed-condition, this analysis identified a main effect of resistance, $F(2,86) = 352.23$, $p <.001$, $\eta_p^2 = .89$, but no main effect of age, $F(1,43) < 1$, or an age x resistance interaction, $F(2,86) = 1.64$, $p = .20$. In the non-informed condition, there was a main effect of resistance, $F_{(2,80)}$= 96.27, p <.001, η_p^2 = .71, but no main effect of age, F(1,40) = 1.44, p = .24. Critically, there was an age x resistance interaction, F(2,80) = 7.46, p = .001, η_p^2 = .16. Independent samples t tests with a Holm Bonferroni correction indicated that adolescents inflated the low-resistance balloons more than the adults did, $t_{(40)}$= 2.48, p < .05, d = .78, (Adolescents : M = 4.27, SD = 1.09; Adults: M = 3.46, SD = .99); however, the adolescents inflated the high-resistance balloons less than the adults did, $t_{(40)}$= 2.29, p < .05, d = .72 (Adolescents: M = 7.91, SD = 2.83; Adults: M = 9.96, SD = 2.94). For the middle-resistance balloons, there was no significant age difference, $t_{(40)}$= .72, p = .47 (Adolescents: M = 6.99, SD = 1.65; Adults: M = 7.33, SD = 1.34).

In summary, the developmental effect on the number of pumps depended on the uncertainty level and balloons' resistance. At the end of the game, there were no age differences in the number of pumps for the informed condition. In the non-informed condition, the adolescents presented more pumps than adults in the low-resistance condition and fewer pumps than adults in the high-resistance condition (Figure 2).

[FIGURE 2]

Learning analysis

To further understand the developmental differences observed in the non-informed condition, we calculated a "Distance from Optimal Strategy" score (DOS) indicating the distance between participant's pumps number and the optimal pumps number for each resistance (i.e., the average number of pumps that is associated with maximal expected earning: 3.5 pumps for the low-resistance balloons, 7 pumps for the medium-resistance balloons and 12 pumps for the high-resistance balloons). Indeed, a DOS score near zero indicates an optimal adaptation to resistance (i.e., minimal distance between participant's pumps number and the optimal pumps number), whereas a higher DOS score indicates a poorer adjustment. To explore learning trajectories depending on age, we performed a global ANOVA on this DOS score with age, information level and gender as the three between-subject factors and balloon resistance and block (5: Block 1, 2, 3, 4, 5) as two within-subject factors (Figure 3). This ANOVA revealed an Age x Information x Block x Resistance interaction, $F(2,158) = 2.89, p < .01, \eta_p^2 = .04$, that was not modulated by gender, $F(8,632) = 1.01, p = .42$. Then this three-way interaction was followed up using two independent ANOVAs for the informed and non-informed conditions.

In the informed condition (Figure 3), this analysis identified a main effect of resistance, $F(2,86) = 44.23, p <.001, \eta_p^2 = .51$, indicating that DOS score increased with resistance (low-resistance: $M = 1.00$, $SD = .11$; medium-resistance: $M = 1.61$, $SD = .17$; and high-resistance: $M = 2.64$, $SD = .49$), and a main effect of block, $F(4,172) = 9.27, p < .001, \eta_p^2 = .18$, indicating that DOS score linearly decreased over blocks, $F(1,43) = 16.49, p < .001$, (block 1: $M = 2.14$, $SD = .25$; block 2: $M = 1.76$, $SD = .19$; block 3: $M = 1.68$, $SD = .19$; block 4: $M = 1.64$, $SD = .19$; block 5: $M = 1.52$, $SD = .15$). However, there was also a block x resistance interaction, $F(8,344) = 5.35, p < .001, \eta_p^2 = .11$. Planned contrasts revealed an effect of block for the low-resistance balloons, $F(4,176) = 3.34, p < .05, \eta_p^2 = .08$, and high-resistance balloons, $F(4,176) = 9.07, p < .001, \eta_p^2 = .17$, but not for medium-resistance balloons, $F(4,176) = 1.47, p = .21, \eta_p^2 = .03$. The DOS score was higher in the first block than in the other blocks for the low-resistance balloons (all $p > .01$) (block 1: $M = 1.18$, $SD = .06$; block 2: $M = .95$, $SD = .06$; block 3: $M = .96$, $SD = .08$; block 4: $M = .95$, $SD = .06$; block 5: $M = .94$, $SD = .07$), and followed a linear trend for the high-resistance balloons, $F(1,44) = 15.41, p < .001$ (block 1: $M = 3.48$, $SD = .27$; block 2: $M = 2.74$, $SD = .27$; block 3: $M = 2.38$, $SD = .26$; block 4: $M = 2.41$, $SD = .28$; block 5: $M = 2.17$, $SD = .22$). Critically, there was neither a main effect of age, $F(1,43) < 1$, age x bloc interaction, $F(4, 172) = 1.36, p = .25$, age x resistance interaction, $F(2, 86) = 0.15, p =$

.86, nor an age x bloc x resistance interaction, $F(8, 344) = 1.18$, $p = .31$.

In the non-informed condition (Figure 3), this analysis identified a main effect of resistance, $F(2,80) = 85.51$, $p <.001$, $\eta_p^2 = .69$, indicating that the DOS score increased with resistance (low-resistance: $M = 1.00$, $SD = .11$; medium-resistance: $M = 1.61$, $SD = .17$; and high-resistance: $M = 2.64$, $SD = .49$), and a main effect of block, $F(4,160) = 93.92$, $p < .01$, $\eta_p^2 = .09$ (block 1: $M = 2.44$, $SD = .24$; block 2: $M = 2.14$, $SD = .26$; block 3: $M = 2.04$, $SD = .28$; block 4: $M = 2.21$, $SD = .31$; block 5: $M = 2.04$, $SD = .27$) but no resistance x age interaction, $F(2, 80) = 2.27$, $p = .11$, $\eta_p^2 = .05$,. There was a marginally main effect of age, $F(1,40) = 3.61$, $p = .06$, $\eta_p^2 = .08$ (adolescents: $M = 2.44$, $SD = .19$; adults: $M = 1.91$, $SD = .21$), a block x age interaction, $F(4, 160) = 4.71$, $p < .01$, $\eta_p^2 = .10$, and critically an age x block x resistance interaction, $F(8, 320) = 2.70$, $p < .01$, $\eta_p^2 = .06$ (Figure 3). For the low-resistance balloons, adolescents showed a higher DOS score than adults did, $F(1,40) = 5.26$, $p <.05$, $\eta_p^2 = .11$ (adolescents: $M = 1.06$, $SD = .12$; adults: $M = .89$, $SD = .13$), but this score followed a quadratic trend for both adolescents, $F(1,38) = 24.84$, $p <.001$ (block 1: $M =1.17$, $SD = .06$; block 2: $M = .78$, $SD = .08$; block 3: $M = .86$, $SD = .09$; block 4: $M = 1.16$, $SD = .08$; block 5: $M = 1.30$, $SD = .09$), and adults, $F(1,38) = 14.23$, $p <.001$ (block 1: $M =1.12$, $SD = .06$; block 2: $M = .74$, $SD = .09$; block 3: $M = .73$, $SD = .09$; block 4: $M = 0.90$, $SD = .09$; block 5: $M = .91$, $SD = .11$). For the medium-resistance balloons, there was neither an age effect, $F(1,40) = 1.45$, $p = .23$, nor an effect of Block, $F(4,160) = 1.12$, $p = .34$, $\eta_p^2 = .03$. Finally, developmental differences appear for the high-resistance balloons: The DOS score decreases following a linear trend for adults, $F(1,40) = 12.71$, $p <.001$ (block 1: $M =4.66$, $SD = .53$; block 2: $M = 3.77$, $SD = .54$; block 3: $M = 3.63$, $SD = .60$; block 4: $M = 3.03$, $SD = .60$; block 5: $M = 2.62$, $SD = .54$), whereas there was no effect of block among adolescents, $F(4, 72) < 1$ (block 1: $M =4.77$, $SD = .48$; block 2: $M = 4.51$, $SD = .49$; block 3: $M = 4.54$, $SD = .55$; block 4: $M = 5.14$, $SD = .54$; block

5: M = 4.46, SD = .49).

[FIGURE 3]

In summary, this analysis revealed that adolescents and adults learned similarly to adjust risk-taking to the resistance over blocks in the informed condition. However, in the non-informed condition, adolescents showed a poorer adjustment level than adults, especially for the low-resistance balloons and the high-resistance balloons, for which only adults displayed an improved adjustment over blocks.

Discussion

Using a new adaptation of the BART, the present study aimed to clarify whether explicit versus implicit risk information influences risk-taking behaviors in adolescents. Three major results emerged from this investigation: (1) The provision of explicit information regarding the risk level associated with each balloon allows adolescents to be as efficient as adults at the end of the game in the informed condition. 2) In contrast, whereas adolescents and adults performed at the same level in the first blocks, adolescents' ability to adjust risk-taking to the balloon resistance in the non-informed condition remains suboptimal compared with that of adults at the end of the game. 3) This age difference in the non-informed condition did not result from a general excess of risk-taking regardless of the balloon resistance.

The results confirmed that the adolescents performed similarly to the adults when they received explicit information regarding the level of risk (i.e., resistance of a balloon). In the informed condition, the adolescents and adults succeeded in using the given information to adjust the number of pumps at the end of the task. Indeed, adolescents inflated balloons at the same level as adults regardless of balloons' resistance, and both age groups learned progressively to adjust risk-taking to the resistance over blocks in the informed condition. This result is consistent with previous studies that examined the development of probability understanding in risky decision-making. Children and adolescents are able to make advantageous choices between two options that depict different probabilities and values, or to estimate the expected value of gambles (Falk & Wilkening, 1998; Schlottmann, 2001; van Leijenhorst et al., 2008).

Crucially, developmental differences appeared at the end of the game in the non-informed condition. Consistent with expectations, whereas adolescents and adults performed similarly in the first blocks, the adults succeeded more than adolescents in learning the matching of the colors with the balloons' resistance levels based on feedback obtained during the game. This result is consistent with existing evidence that adults progressively learn to make advantageous choices in ambiguous situations (Aïte et al., 2012, Bechara, Damasio, Damasio & Anderson, 1994; Cassotti et al., 2011; Cassotti & Moutier, 2010; van Duijvenvoorde et al., 2011; van Duijvenvoorde, Jansen, Griffioen, Van der Molen, & Huizenga, 2013). However, it is important to note that even if they performed better than adolescents did, adults did not adjust pump action sufficiently based on feedback in the non-informed version. Adults performed only an average of 10 pumps for the high-resistance balloons when the optimal pump number was 12 pumps (i.e., the average number of pumps that is associated with optimal expected earning at the end of the game). This finding is not surprising given that previous studies have already reported an inherent limitation of the BART: individuals should inflate balloons more under the optimal strategy, but they rarely actually perform enough pumps during a given trial to maximize their outcomes (Lejuez et al., 2002; Pleskac, Wallsten, Wang, & Lejuez, 2008). This is also in line with previous studies showing that adults are risk averse for gains (Osmont, Cassotti, Agogué, Houdé, & Moutier, 2015; Reyna, Estrada, DeMarinis, Myers, Stanisz, & Mills, 2011). However, learning analysis revealed that adults continue to learn in the last blocks, suggesting that additional trials might allow them to further adjust their behavior.

In contrast, the adolescents presented an overall impaired feedback-based learning ability compared with that of the adults in the non-informed version of the task. Indeed, analyses of pumps revealed that adolescents inflated the low-resistance balloons more than the adults, and inflated the high-resistance balloons less than the adults. Learning analysis also underlined that adolescents showed a poorer adjustment to the balloons' resistance throughout the game. For the low-resistance balloons, adolescents showed a higher Distance from the Optimal Strategy than adults during the entire game. Moreover, in contrast with adults who linearly improved their DOS score for the high-resistance balloons throughout the game, there was no block effect in adolescence. Note that the lack of DOS score improvement may reflect floor effects in adults that could mask developmental effects for the low and medium balloons. Crucially, higher DOS scores in adolescents do not necessarily imply more risk-taking; a higher distance from the optimal strategy could reflect a lower number of pumps as much as a higher number. Taken together, analyses of pumps and DOS scores provided further information about adolescents' behaviors. These analyses showed a sub-optimal adjustment to balloons' resistance by taking too much risk for the low-resistance balloons, and saving points for the high-resistance balloons earlier than adults at the end of the game. The fact that the 14- to 16-year-old teenagers of the present study failed to infer the risk level of balloon explosion from feedback may appear surprising in light of previous studies that have reported the advantageous pattern of choices made by adolescents from the age of 12 in ambiguous situations (van Duijvenvoorde et al., 2011). However, this result corroborates the findings of previous studies: The ability to make long-term advantageous choices continues to develop until late adolescence (Aïte et al., 2012; Cassotti et al., 2011; Crone & van der Molen, 2004; Crone & van Der Molen, 2007; Crone, Bunge, Latenstein, & van der Molen, 2005; Hooper et al., 2004; Overman et al., 2004). These finding are also in line with developmental studies on feedback learning showing that performance on experimental switch tasks or the WCST increases during childhood and adolescence (Huizinga, Dolan, & van der Molen, 2006 ; Peters, Braams, Raijmakers, Koolschijn, & Crone, 2014 ; Peters, Koolschijn, Crone, Van Duijvenvoorde, & Raijmakers, 2014).

Although it is difficult to determine whether specific behavior in the BART is related to the anticipation of rewards or risk of losses (see Figner, Mackinlay, Wilkening, & Weber, 2009 for a discussion of this limit of the BART and the IGT), the manipulation of rewards' magnitude (i.e., pump rewarded by 1, 5 or 10 points) allows us to indirectly assess whether participants' risk-taking rests on a focus on potential gains or a focus on risk of losses (Bornovalova et al., 2009). Indeed, we reasoned that if a participant focuses on the potential gains, risk-taking would increase alongside the magnitude of reward, given that the potential gain associated with an additional pump is larger in the high-magnitude condition (i.e. a potential gain of 10 points) than in the small-magnitude condition (i.e. a potential gain of 1 point). Conversely, a focus on the risk of losses involves a decrease in risk-taking alongside the magnitude of risk, with an additional pump resulting in a larger loss in the high-magnitude condition than in the small-magnitude condition. In accord with the results of Bornovalova et al. (2009), risk taking in the present study seems to be driven more by the risk of losses than by potential gains, with fewer pumps occurring for larger chip rewards. Nevertheless, the lack of developmental differences found regarding this chip value effect suggests that adolescents' difficulties with the non-informed version of the task might not result from specificity in a rewards versus negative outcomes focus. Given the absence of effective losses in our adaptation of the BART (e.g., a no-gain but no removal of the accumulated points in the temporary bank from the definitive bank after an explosion), the observed decrease in risk taking for larger chip rewards is in line with numerous previous studies showing risk aversion in the domain of gains (Osmont, Cassotti, Agogué, Houdé, & Moutier, 2015; Reyna, Estrada, DeMarinis, Myers, Stanisz, & Mills, 2011).

In addition, our results are in accord with the Fuzzy trace theory (Reyna, Wilhelms, McCormick, & Weldon, 2015), one of the leading theoretical models of adolescents' decision-making that is supported by converging empirical evidence (see Defoe, Dubas, Figner, & van Aken, 2015 for a meta-analysis). Indeed, Fuzzy trace theory opposes two different decision-making processes called detail-oriented verbatim processes (e.g., precise representation of probabilities) and gist-based intuition (e.g., qualitative representation of probabilities). Critically, the Fuzzy trace theory predicts that 1) both detail-oriented verbatim processes and the ability to remember the gist of information develop with age and 2) that gist-based intuition increasingly becomes the default mode of processing (Reyna, 2006; Reyna et al., 2015). In line with the fuzzy trace theory, our results suggest that adolescents may fail to develop a qualitative representation (i.e. gist based process) of risk level for each balloon (i.e., low-risk balloon, medium-risk balloon and high-risk balloon) based on the positive and negative outcomes obtained during the non-informed version of the BART. In contrast, when such qualitative information about the risk level of each balloon is explicitly provided to the participants in the informed condition, both adolescents and adults learned progressively to adjust risk-taking to the resistance over blocks.

Finally, our results do not provide evidence in support of the hypothesis that assumes higher curiosity in the face of the unknown that could lead adolescents to further explore ambiguous situations and then take more risks (Tymula et al., 2012). According to this hypothesis, we could expect a higher level of risk-taking in adolescents as soon as the task begins (i.e., when the ambiguity level is maximal). In this study, developmental effects appeared primarily during the last blocks of the BART. Moreover, adolescents did not present a general excess of risk-taking in the non-informed BART: they exhibited a specific failure to adjust risk-taking based on the feedback they received during the game. More specifically, they took less risk when the risk was favorable (i.e., high-resistance balloons) and too much risk when the risk was disadvantageous (i.e., low resistant-balloons).

In conclusion, the information about risk heavily influenced adolescent risk-taking engagement. Adolescents are efficient in making advantageous choices when explicit information regarding risk is provided; however, they exhibit difficulties in estimating the probabilities of the potential outcomes when information is not directly provided and must be inferred from experience. This finding seems to suggest that adolescents could learn from feedback but may need further explicit guidance to learn from their own experiences. Critically, this specific failure is not a consequence of an increased ambiguity tolerance but rather reflects a specific impairment of feedback-based learning ability. This research supplements previous studies by underlying the existence of cognitive specificities during adolescence that are crucial for risky decision making and have to be considered by prevention programs that aim to reduce reckless behaviors in teenagers (Reyna & Farley, 2006). Nonetheless, an increasing body of research suggests a key role of socio-emotional context in adolescent decision-making (Cavalca et al., 2013; Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; Gardner & Steinberg, 2005; Haddad, Harrison, Norman & Lau, 1014; O'Brien, Albert, Chein, & Steinberg, 2011; Reynolds, MacPherson, Schwartz, fox & Lejuez, 2013; Teunissen et al., 2012, 2013) and indicates that peer presence or social comparison strongly influence risk-taking behavior even when information regarding the probabilities of the potential outcomes is available (Smith, Chein & Steinberg, 2014). Thus, future research ought to explore whether socio-emotional context could influence adolescents' learning abilities in informed and non-informed risk-taking situations (Blankenstein, Crone, Bos, & van Duijvenvoorde, 2016). More specifically, given that our results highlight that immature decision making in non informed situations is due to the difficulty adolescents have in learning the risk level of an option from their own experience, there is an urgent need to examine whether previous experiences of others such as peers or adults may facilitate the development of a qualitative representation of risk level in ambiguous circumstances.

Bibliography

Aïte, A., Cassotti, M., Rossi, S., Poirel, N., Lubin, A., Houdé, O., & Moutier, S. (2012). Is human decision making under ambiguity guided by loss frequency regardless of the costs? A developmental study using the Soochow Gambling Task. *Journal of Experimental Child* Psychology, 113(2), 286–294. DOI: 10.1016/j.jecp.2012.05.008

Bechara, A., Damasio, A. R., Damasio, H., & Anderson, S. W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition, 50*(1-3), 7–15. DOI: 10.1016/0010-0277(94)90018-3

Bishara, A.J., Pleskac, T.J., Fridberg, D.J., Yechiam, E., Lucas, J., Busemeyer, J.R., et al. (2009). Similar processes despite divergent behavior in two commonly used measures of risky decision making. J*ournal of Behavioral Decision Making, 22* (4), 435–454. DOI: 10.1002/bdm.641

Blankenstein, N. E., Crone, E. A., Bos, W. van den, & Duijvenvoorde, A. C. K. van. (2016). Dealing With Uncertainty: Testing Risk- and Ambiguity-Attitude Across Adolescence. *Developmental Neuropsychology, 41*(1-2), 77–92. DOI: 10.1080/87565641.2016.1158265

Bornovalova, M. A., Cashman-Rolls, A., O'Donnell, J. M., Ettinger, K., Richards, J. B., deWit, H., & Lejuez, C. W. (2009). Risk taking differences on a behavioral task as a function of potential reward/loss magnitude and individual differences in impulsivity and sensation seeking. *Pharmacology Biochemistry and Behavior, 93*(3), 258–262. DOI: 10.1016/j.pbb.2008.10.023

Casey, B. J., Getz, S., & Galvan, A. (2008). The adolescent brain. *Developmental Review, 28*(1), 62–77. DOI: 10.1016/j.dr.2007.08.003

Cassotti, M., Aïte, A., Osmont, A., Houdé, O., & Borst, G. (2014). What have we learned about the processes involved in the Iowa Gambling Task from developmental studies? *Frontiers in Psychology, 5*, 915. DOI: 10.3389/fpsyg.2014.00915

Cassotti, M., Houdé, O., & Moutier, S. (2011). Developmental changes of win-stay and loss-shift strategies in decision making. *Child Neuropsychology, 17*(4), 400–411. DOI: 10.1080/09297049.2010.547463

Cassotti, M., & Moutier, S. (2010). How to explain receptivity to conjunction-fallacy inhibition training: Evidence from the Iowa Gambling Task. *Brain and Cognition, 72*(3), 378–384. DOI: 10.1016/j.bandc.2009.11.004

Cavalca, E., Kong, G., Liss, T., Reynolds, E. K., Schepis, T. S., Lejuez, C. W., & Krishnan-Sarin, S. (2013). A preliminary experimental investigation of peer influence on risk-taking among adolescent smokers and non-smokers. *Drug and Alcohol Dependence, 129*(1-2), 163–166. DOI: doi.org/10.1016/j.drugalcdep.2012.09.020

Chein, J., Albert, D., O'Brien, L., Uckert, K., & Steinberg, L. (2011). Peers increase adolescent risk taking by enhancing activity in the brain's reward circuitry: Peer influence on risk taking. *Developmental Science, 14*(2), F1–F10. DOI: 10.1111/j.1467-7687.2010.01035.x

Crone, E. A., & van der Molen, M. (2004). Developmental Changes in Real Life Decision Making: Performance on a Gambling Task Previously Show to Depend on the Ventromedial Prefrontal Cortex. *Developmental Neuropsychology, 25*(3), 251–279.

Crone, E. A., & Van Der Molen, M. W. (2007). Development of Decision Making in School-Aged Children and Adolescents: Evidence From Heart Rate and Skin Conductance Analysis. *Child Development, 78*(4), 1288–1301.

Crone, E., Bunge, S., Latenstein, H., & van der Molen, M. (2005). Characterization of Children's Decision Making: Sensitivity to Punishment Frequency, Not Task Complexity. *Child Neuropsychology, 11*(3), 245–263. DOI: 10.1080/092970490911261

Dean, A. C., Sugar, C. A., Hellemann, G., & London, E. D. (2011). Is all risk bad? Young adult cigarette smokers fail to take adaptive risk in a laboratory decision-making test. *Psychopharmacology, 215*(4), 801–811. DOI: 10.1007/s00213-011-2182-y

Defoe, I. N., Dubas, J. S., Figner, B., & van Aken, M. A. (2015). A meta-analysis on age differences in risky decision making: Adolescents versus children and adults. *Psychological Bulletin, 141*(1), 48-84. DOI: 10.1037/a0038088.

Falk, R., & Wilkening, F. (1998). Children's construction of fair chances: adjusting probabilities. *Developmental Psychology, 34*(6), 1340.

Figner, B., Mackinlay, R. J., Wilkening, F., & Weber, E. U. (2009). Affective and deliberative processes in risky choice: age differences in risk taking in the Columbia Card Task. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*(3), 709.

Galvan, A., Hare, T., Voss, H., Glover, G., & Casey, B. J. (2007). Risk-taking and the adolescent brain: who is at risk? *Developmental Science*, *10*(2), F8–F14. DOI: 10.1111/j.1467-7687.2006.00579.x

Gardner, M., & Steinberg, L. (2005). Peer Influence on Risk Taking, Risk Preference, and Risky Decision Making in Adolescence and Adulthood: An Experimental Study. *Developmental Psychology, 41*(4), 625–635. DOI: 10.1037/0012-1649.41.4.625

Haddad, A. D. M., Harrison, F., Norman, T., & Lau, J. Y. F. (2014). Adolescent and adult risk-taking in virtual social contexts. *Frontiers in Psychology, 18*(5), 1476. DOI: 10.3389/fpsyg.2014.01476

Hooper, C. J., Luciana, M., Conklin, H. M., & Yarger, R. S. (2004). Adolescents' Performance on the Iowa Gambling Task: Implications for the Development of Decision Making and Ventromedial Prefrontal Cortex. *Developmental Psychology*, *40*(6), 1148–1158. DOI: 10.1037/0012-1649.40.6.1148

Huizinga, M., Dolan, C. V., & van der Molen, M. W. (2006). Age-related change in executive function: developmental trends and a latent variable analysis. *Neuropsychologia*, *44*(11), 2017–2036. DOI: 10.1016/j.neuropsychologia.2006.01.010

Humphreys, K. L., Lee, S. S., & Tottenham, N. (2013). Not all risk taking behavior is bad: Associative sensitivity predicts learning during risk taking among high sensation seekers. *Personality and Individual Differences, 54*(6), 709–715. DOI: 10.1016/j.paid.2012.11.031

Lejuez, C. W., Aklin, W. M., Zvolensky, M. J., & Pedulla, C. M. (2003). Evaluation of the Balloon Analogue Risk Task (BART) as a predictor of adolescent real-world risk-taking behaviours. *Journal of Adolescence*, *26*(4), 475–479. DOI: 10.1016/S0140-1971(03)00036-8

Lejuez, C. W., Read, J. P., Kahler, C. W., Richards, J. B., Ramsey, S. E., Stuart, G. L., … Brown, R. A. (2002). Evaluation of a behavioral measure of risk taking: The Balloon Analogue Risk Task (BART). *Journal of Experimental Psychology: Applied*, *8*(2), 75–84. DOI: 10.1037//1076-898X.8.2.75

Levin, I. P., Weller, J. A., Pederson, A. A., & Harshman, L. A. (2007). J*udgment and Decision Making*, *2*(4), 225–233.

Levin, I. P., & Hart, S. S. (2003). Risk preferences in young children: early evidence of individual differences in reaction to potential gains and losses. *Journal of Behavioral Decision Making*, *16*(5), 397–413. DOI: 10.1002/bdm.453

O'Brien, L., Albert, D., Chein, J., & Steinberg, L. (2011). Adolescents Prefer More Immediate Rewards When in the Presence of their Peers: Peers and immediate rewards. *Journal of Research on Adolescence*, *21*(4), 747–753. DOI: 10.1111/j.1532-7795.2011.00738.x

Osmont, A., Cassotti, M., Agogué, M., Houdé, O., & Moutier, S. (2015). Does ambiguity aversion influence the framing effect during decision making? *Psychonomic bulletin & review*, *22*(2), 572-577. DOI: 10.3758/s13423-014-0688-0

Overman, W. H., Frassrand, K., Ansel, S., Trawalter, S., Bies, B., & Redmond, A. (2004). Performance on the IOWA card task by adolescents and adults. *Neuropsychologia*, *42*(13), 1838–1851. DOI: 10.1016/j.neuropsychologia.2004.03.014

Pleskac, T. J., Wallsten, T. S., Wang, P., & Lejuez, C. W. (2008). Development of an automatic response mode to improve the clinical utility of sequential risk-taking tasks.

Experimental and Clinical Psychopharmacology, 16(6), 555–564. DOI: 10.1037/a0014245

Peters, S., Braams, B.R., Raijmakers, M.E., Koolschijn, P.C.M.P., Crone, E.A (2014). The neural coding of feedback learning across child and adolescent development. Journal of *Cognitive Neuroscience, 26* (8), 1705-1720.

Peters, S., Koolschijn, P.C.M.P., Crone, E.A., van Duijvenvoorde, A.C.K., Raijmakers, M.E.J. (2014). Strategies influence neural activity for feedback learning across child and adolescent development. Neuropsychologia, 62, 365-374.

Reyna, V. F., Estrada, S. M., DeMarinis, J. A., Myers, R. M., Stanisz, J. M., & Mills, B. A. (2011). Neurobiological and memory models of risky decision making in adolescents versus young adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *37*(5), 1125. DOI: 10.1037/a0023943.

Reyna, V. F., & Farley, F. (2006). Risk and rationality in adolescent decision making implications for theory, practice, and public policy. *Psychological Science in the Public Interest, 7*(1), 1–44.

Reyna, V. F., Wilhelms, E. A., McCormick, M. J., & Weldon, R. B. (2015). Development of Risky Decision Making: Fuzzy-Trace Theory and Neurobiological Perspectives. Child *Development Perspectives, 9*(2), 122-127. DOI: 10.1111/cdep.12117

Reynolds, E. K., MacPherson, L., Schwartz, S., Fox, N. A., & Lejuez, C. W. (2013). Analogue Study of Peer Influence on Risk-Taking Behavior in Older Adolescents. *Prevention Science ,15*(6), 842-9. DOI: 10.1007/s11121-013-0439-x

Schlottmann, A. (2001). Children’s probability intuitions: Understanding the expected value of complex gambles. *Child Development, 72*(1), 103–122.

Smith, A. R., Chein, J., & Steinberg, L. (2014). Peers increase adolescent risk taking even when the probabilities of negative outcomes are known. *Developmental Psychology*, *50*(5), 1564–1568. DOI: 10.1037/a0035696

Spear, L. P. (2000). The adolescent brain and age-related behavioral manifestations. *Neuroscience & Biobehavioral Reviews*, *24*(4), 417–463.

Steinberg, L. (2008). A social neuroscience perspective on adolescent risk-taking. *Developmental Review*, *28*(1), 78–106. DOI: 10.1016/j.dr.2007.08.002

Steinberg, L., & Monahan, K. C. (2007). Age differences in resistance to peer influence. *Developmental Psychology*, *43*(6), 1531–1543. DOI: 10.1037/0012-1649.43.6.1531

Teunissen, H. A., Spijkerman, R., Cohen, G. L., Prinstein, M. J., Engels, R. C. M. E., & Scholte, R. H. J. (2013). An experimental study on the effects of peer drinking norms on adolescents’ drinker prototypes. *Addictive Behaviors, 39*(1), 85–93. DOI: 10.1016/j.addbeh.2013.08.034

Teunissen, H. A., Spijkerman, R., Prinstein, M. J., Cohen, G. L., Engels, R. C. M. E., & Scholte, R. H. J. (2012). Adolescents’ Conformity to Their Peers’ Pro-Alcohol and Anti-Alcohol Norms: The Power of Popularity. *Alcoholism: Clinical and Experimental Research, 36*(7), 1257–1267. DOI: 10.1111/j.1530-0277.2011.01728.x

Tymula, A., Rosenberg Belmaker, L. A., Roy, A. K., Ruderman, L., Manson, K., Glimcher, P. W., & Levy, I. (2012). Adolescents’ risk-taking behavior is driven by tolerance to ambiguity. *Proceedings of the National Academy of Sciences, 109*(42), 17135–17140. DOI:

10.1073/pnas.1207144109

van Duijvenvoorde, A. C., Jansen, B. R., Visser, I., & Huizenga, H. M. (2010). Affective and cognitive decision-making in adolescents. *Developmental Neuropsychology*, *35*(5), 539–554.

Van Duijvenvoorde, A. C. K., Jansen, B. R. J., Bredman, J. C., & Huizenga, H. M. (2011). Age-related changes in decision making: Comparing informed and noninformed situations. *Developmental Psychology*, *48*(1), 192–203. DOI: 10.1037/a0025601

Van Duijvenvoorde, A. C. K., Jansen, B. R. J., Griffioen, E. S., Van der Molen, M. W., & Huizenga, H. M. (2013). Decomposing developmental differences in probabilistic feedback learning: A combined performance and heart-rate analysis. *Biological Psychology*, *93*(1), 175–183. DOI: 10.1016/j.biopsycho.2013.01.006

Van Leijenhorst, L., Westenberg, P. M., & Crone, E. A. (2008). A Developmental Study of Risky Decisions on the Cake Gambling Task: Age and Gender Analyses of Probability Estimation and Reward Evaluation. *Developmental Neuropsychology*, *33*(2), 179–196. DOI: 10.1080/87565640701884287

Weller, J. A., Levin, I. P., & Denburg, N. L. (2011). Trajectory of risky decision making for potential gains and losses from ages 5 to 85. *Journal of Behavioral Decision Making, 24(*4), 331–344. DOI: 10.1002/bdm.690

Table 1

Characteristics of the sample distribution. Gender and mean age distributions for each task condition and age group.

Group	Condition	N	Mean Age (SD)	Boys (Girls)
14-16 years	Informed	22	14.5 (0.7)	12 (10)
	Non-informed	23	14.9 (0.6)	8 (15)
20-25 years	Informed	23	21.8 (1.6)	10 (13)
	Non-informed	19	21.9 (1.4)	9 (10)

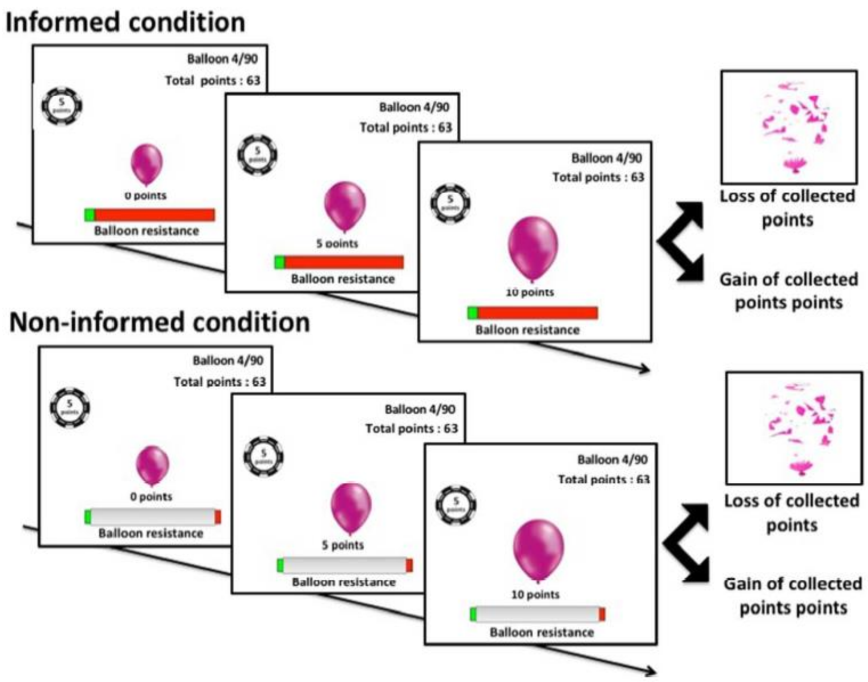

Figure 1: Trial sequence presented in the two information levels (informed and non-informed) for the low-resistance condition.

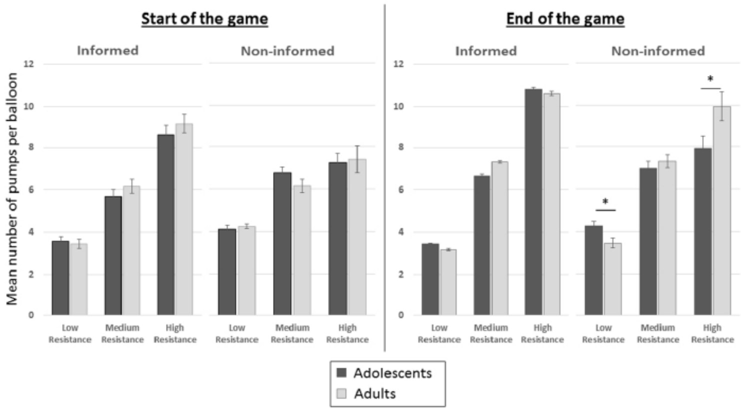

Figure 2: Mean number of pumps per balloon in the informed and non-informed conditions for the first 18 balloons (i.e., start of the game) and the last 18 balloons (i.e., end of the game). * p < .05

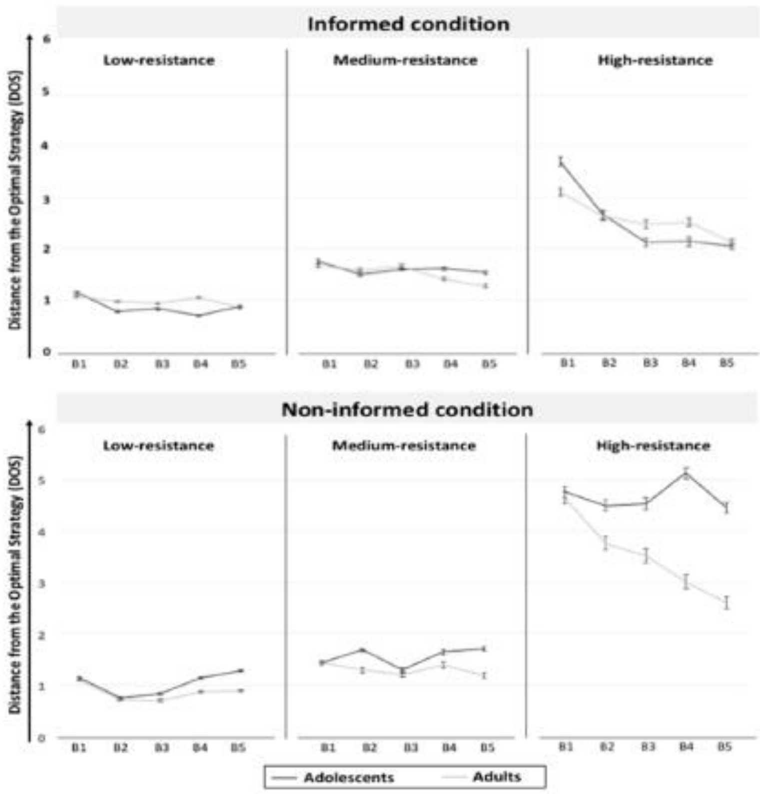

Figure 3: Mean Distance from the Optimal Strategy (DOS score) for the 5 blocks of adolescents and adults. A DOS score near to zero indicates an optimal adaptation to resistance (i.e. minimal distance between participant's pumps number and the optimal pumps number) whereas a higher DOS score indicates a poorer adjustment. * p < .05